FRONTIERS OF HADRONTHERAPY

Ugo Amaldi and <u>Saverio Braccini</u>

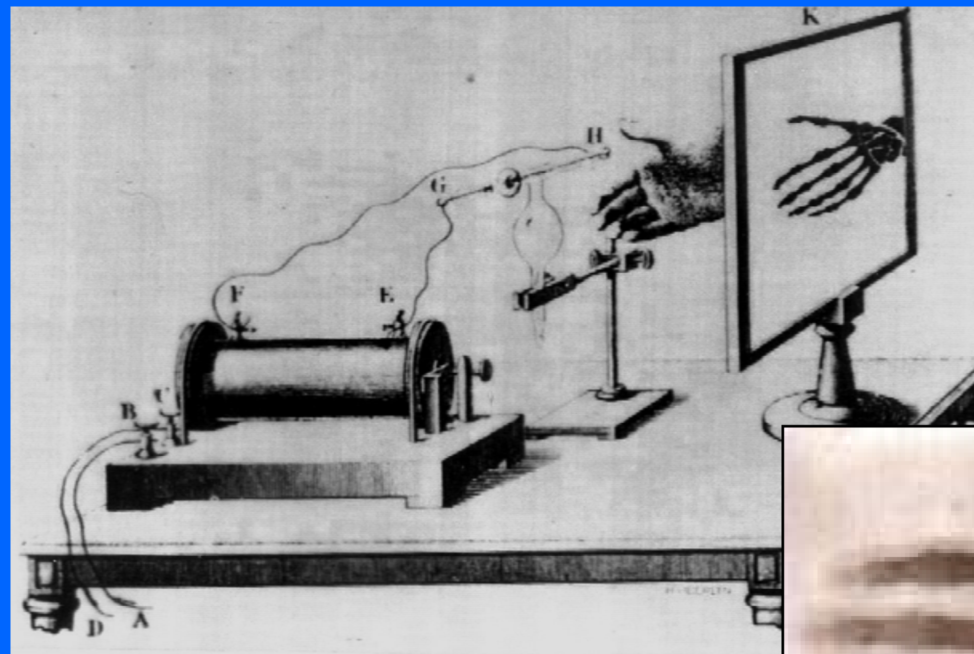
TERA
Foundation for Oncological Hadron-therapy

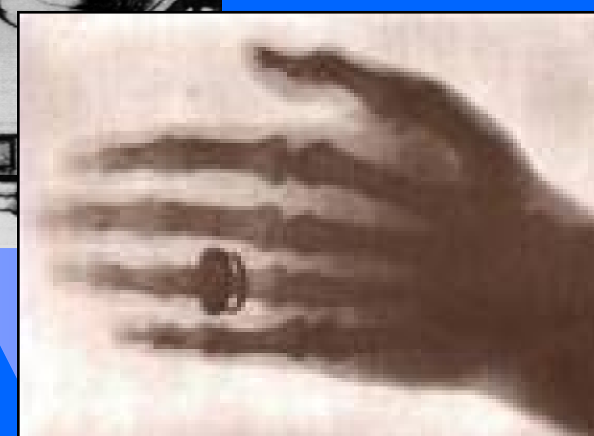
Outline

- Introduction: fundamental research in particle physics and medical applications
- Conventional radiation therapy with X rays
- Hadrontherapy, the new frontier of cancer radiation therapy
  - Proton-therapy
  - Carbon ion therapy
- Some new ideas for the future:
  - CYCLINACs
  - Laser plasma based accelerators?
- Conclusions and outlook

- November 1895 : discovery of X rays

Wilhelm Conrad Röntgen





- December 1895 : first radiography
- First application of *photons* to medicine much before 1905 and light quanta!

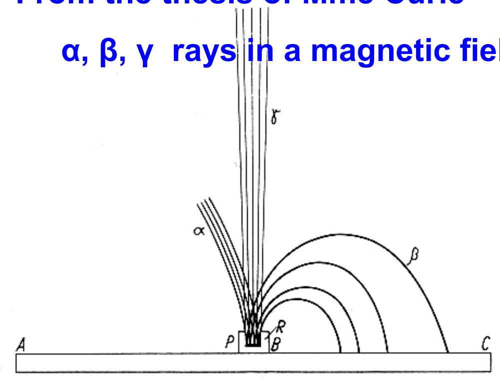
- **1896 : discovery of natural radioactivity**

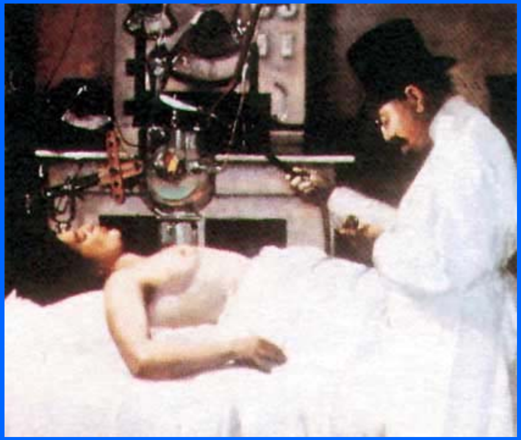
Henri Bequerel

Maria Skłodowska-Curie and Pierre Curie

From the thesis of Mme Curie – 1904

α, β, γ rays in a magnetic field





- **1908 : first attempts of skin cancer radiation therapy ("*Curietherapy*")**

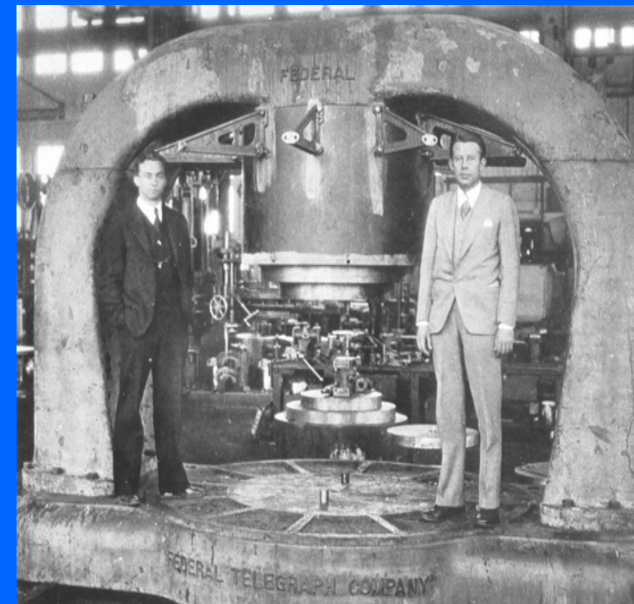
A big step forward…

…in particle physics and in

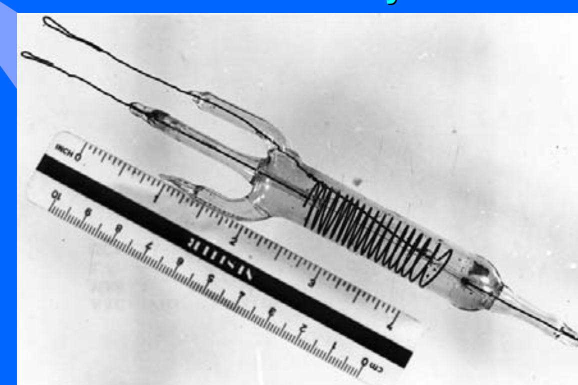
- Medical diagnostics
- Cancer radiation therapy

due to the development of three fundamental tools

- Particle accelerators
- Particle detectors
- Computers



M. S. Livingston and E. Lawrence with the 25 inches cyclotron

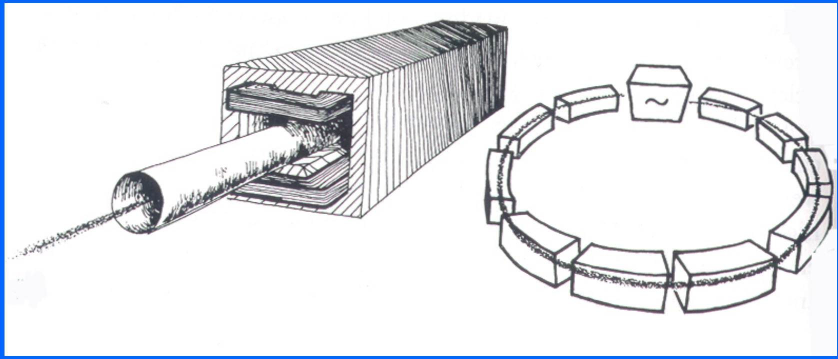


Geiger-Müller counter built by E.Fermi and his group in Rome

1945: E. McMillan and V.J.Veksler *The synchrotron*

discover the

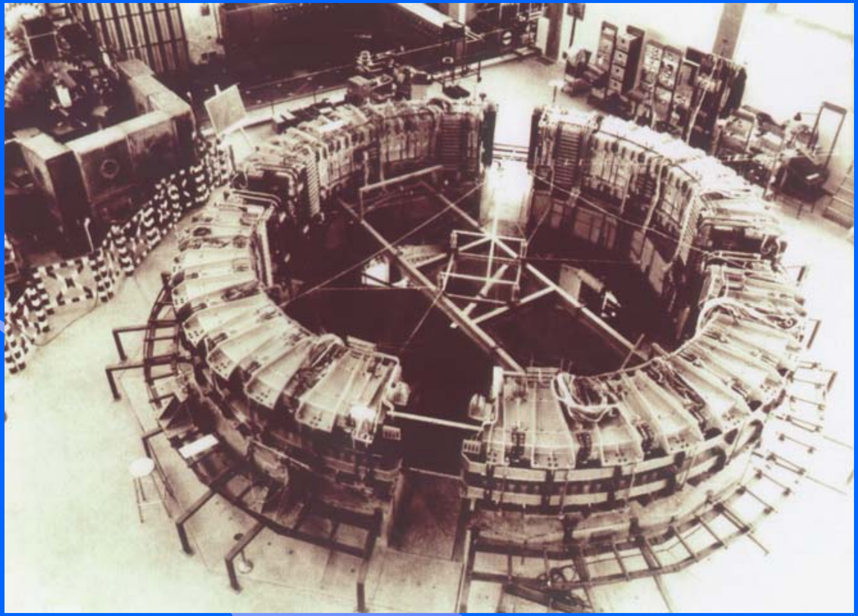
principle of phase stability



1959: Veksler visits McMilan at Berkeley

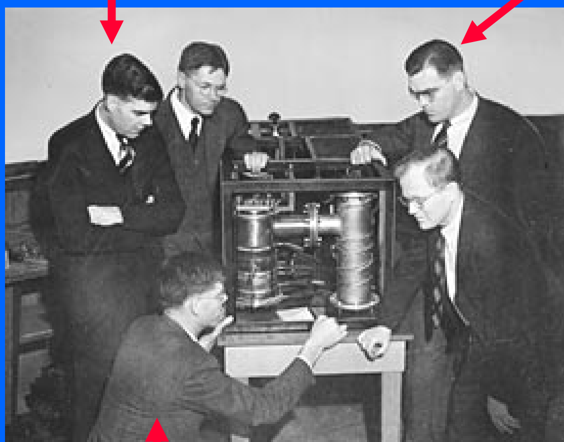
1 GeV electron synchrotron

Frascati - INFN - 1959



Sigurd Varian

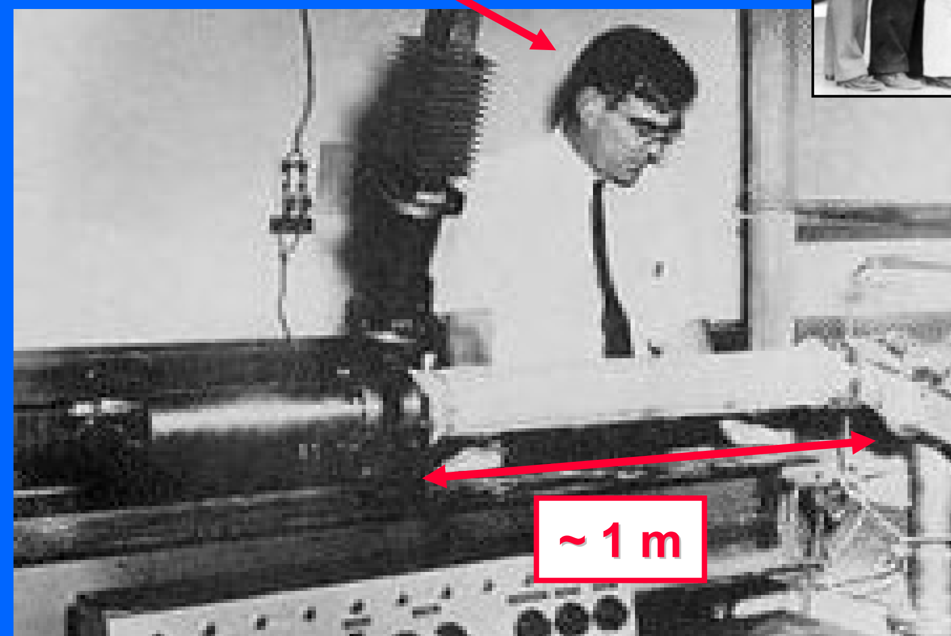
William W. Hansen



Russell Varian

1939

Invention of the klystron



1947
first linac for electrons
4.5 MeV and 3 GHz

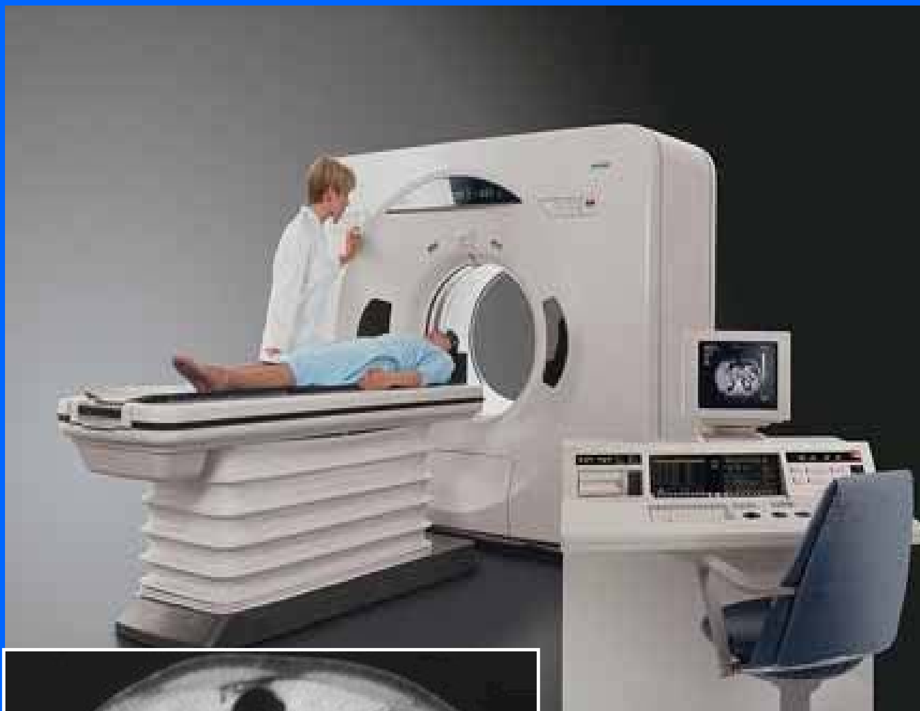
Accelerators running in the world

CATEGORY OF ACCELERATORS	NUMBER IN USE (*)	
High Energy acc. (E >1GeV)	~120	
Synchrotron radiation sources	>100	
Medical radioisotope production	~200	9000
Radiotherapy accelerators	> 7500	
Research acc. included biomedical research	~1000	
Acc. for industrial processing and research	~1500	
Ion implanters, surface modification	>7000	
TOTAL	> 17500	

(*) W. Maciszewski and W. Scharf: Int. J. of Radiation Oncology, 2004

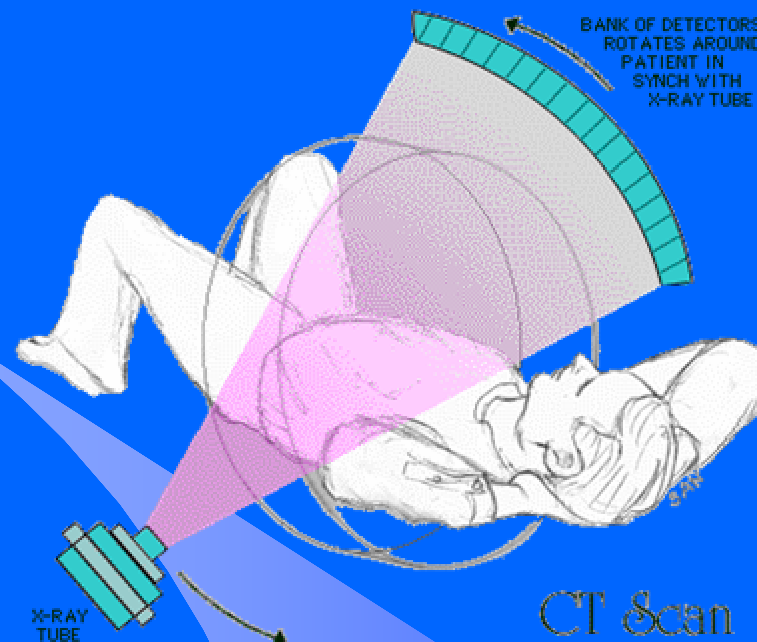
- **About half are used for bio-medical applications**

Diagnostics is essential!



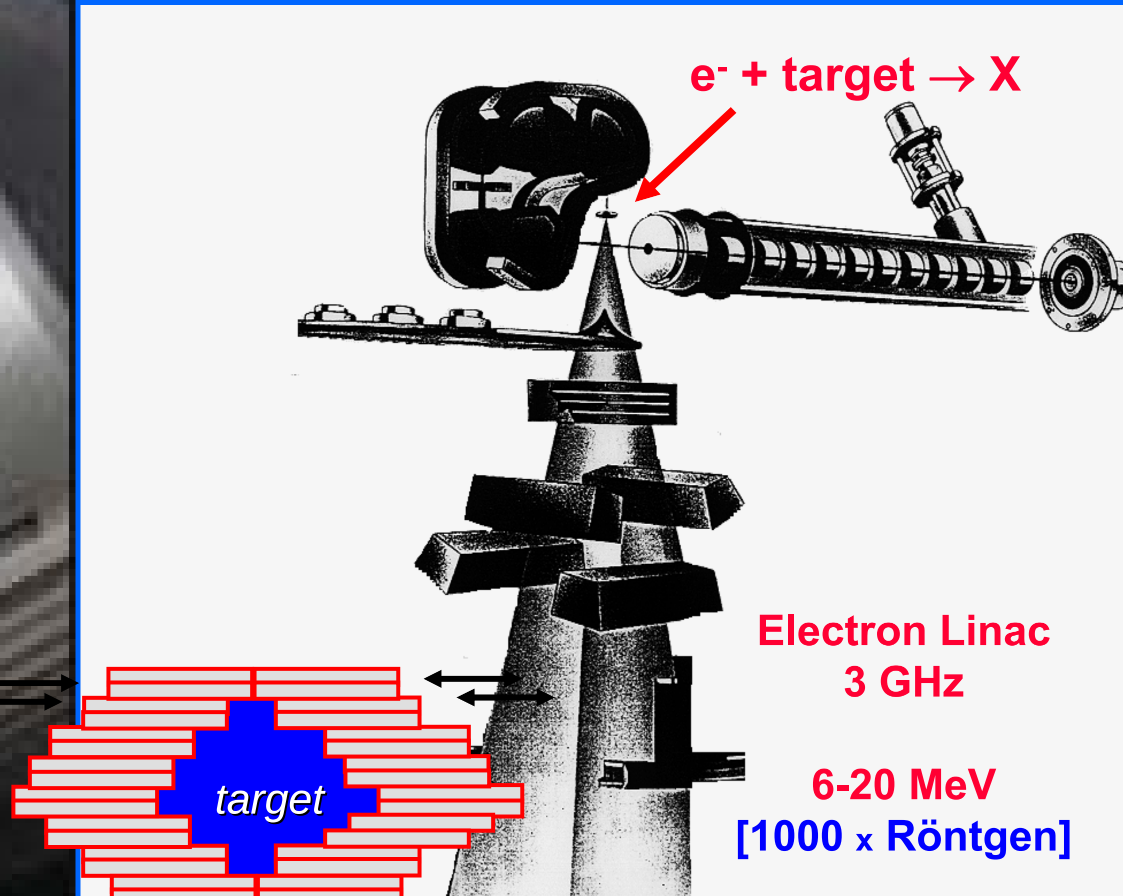
Abdomen

Computer Tomography (CT)



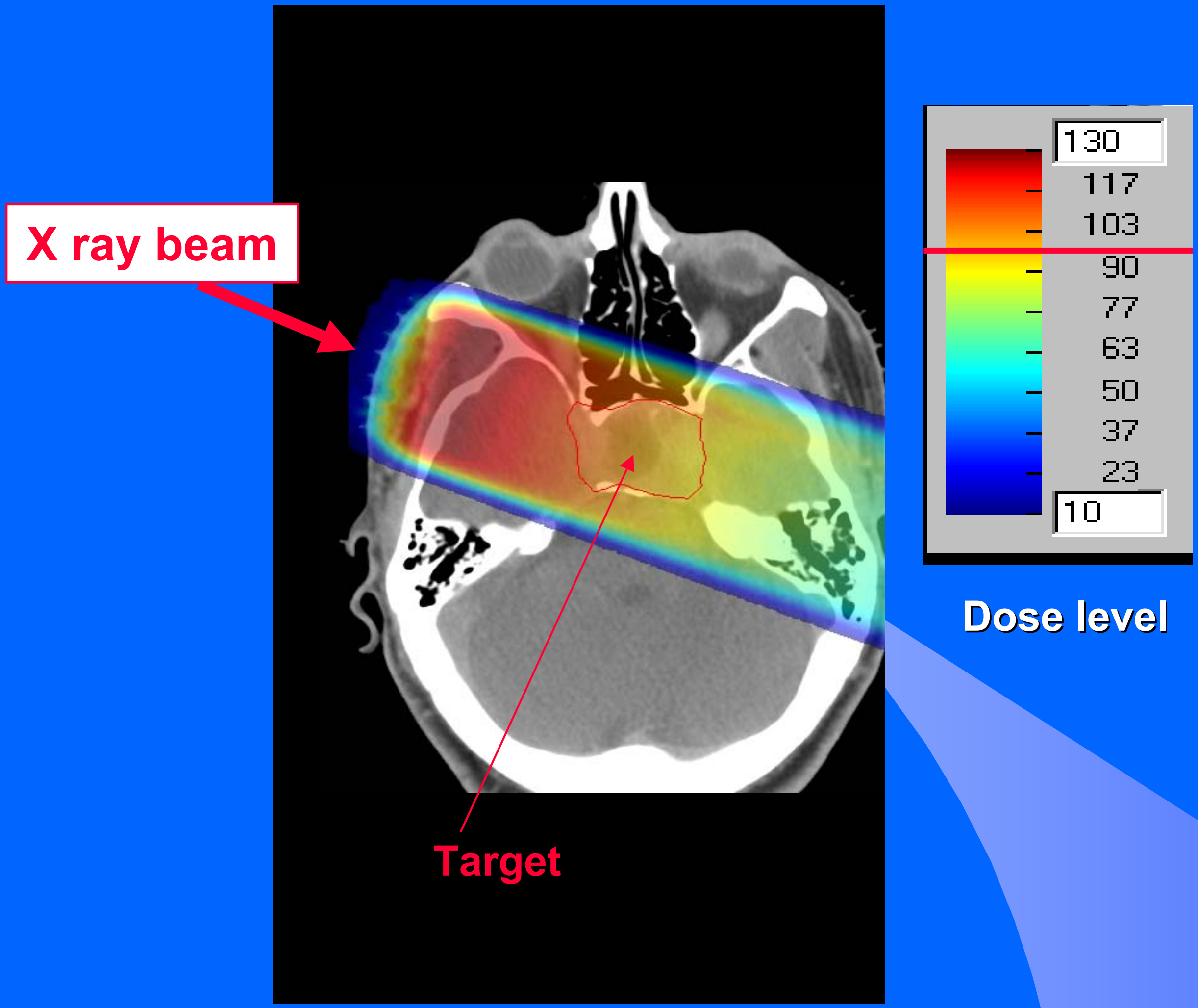
- **Measurement of the electron density**
- **Information on the morphology**

Radiotherapy with X-rays



- **Electron linacs to produce gamma rays (called X-rays by medical doctors)**
- **20'000 patients/year every 10 million inhabitants**

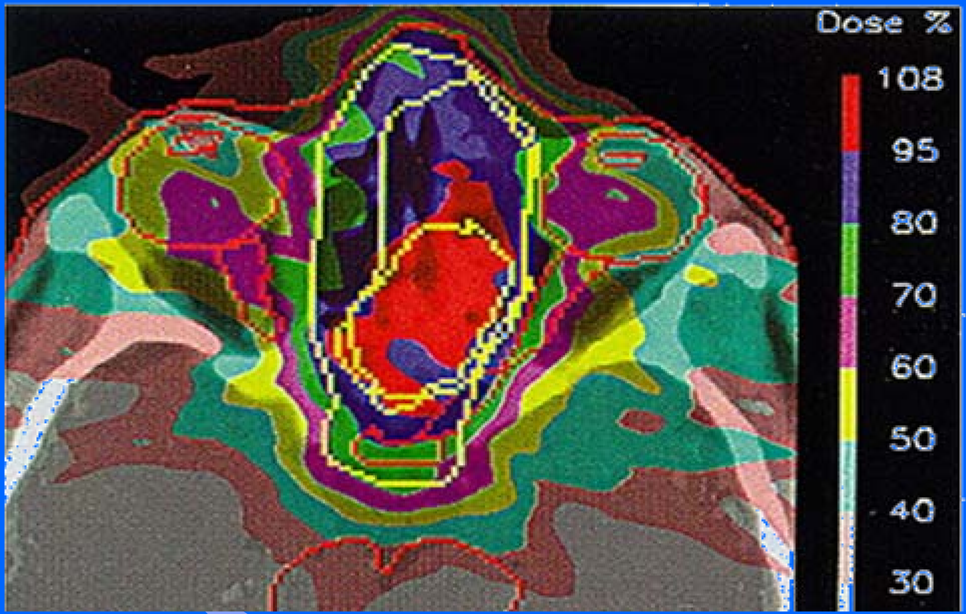
The problem of X ray therapy



The problem of X ray therapy

Solution:

- **Use of many crossed beams**
- **Intensity modulation (IMRT)**



9 different photon beams

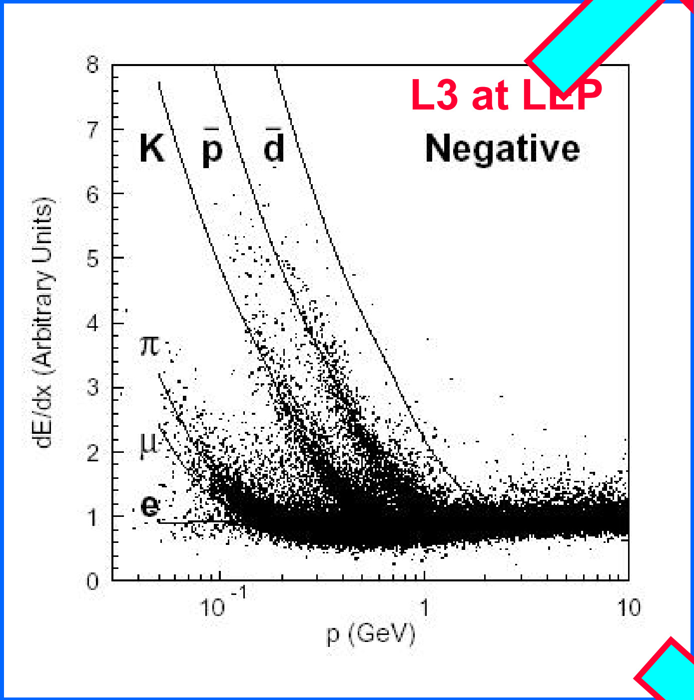
The limit is due to the dose given to the healthy tissues!

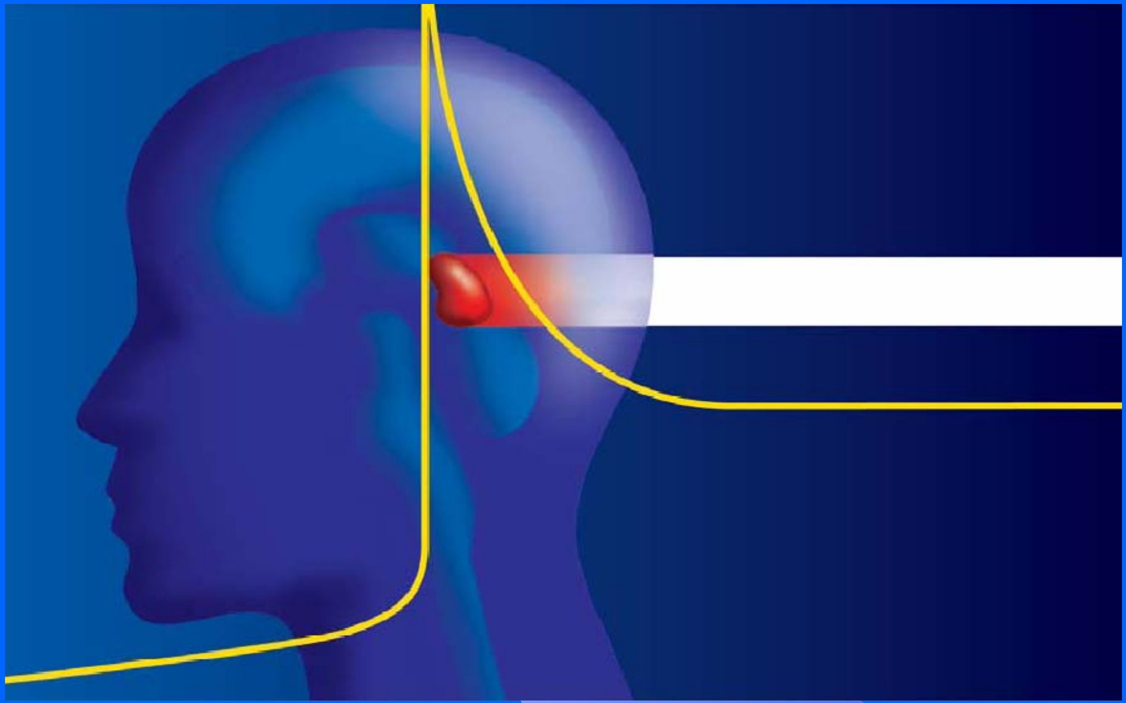
Especially near organs at risk (OAR)

Let's go back to physics...

Fundamental physics

Particle identification

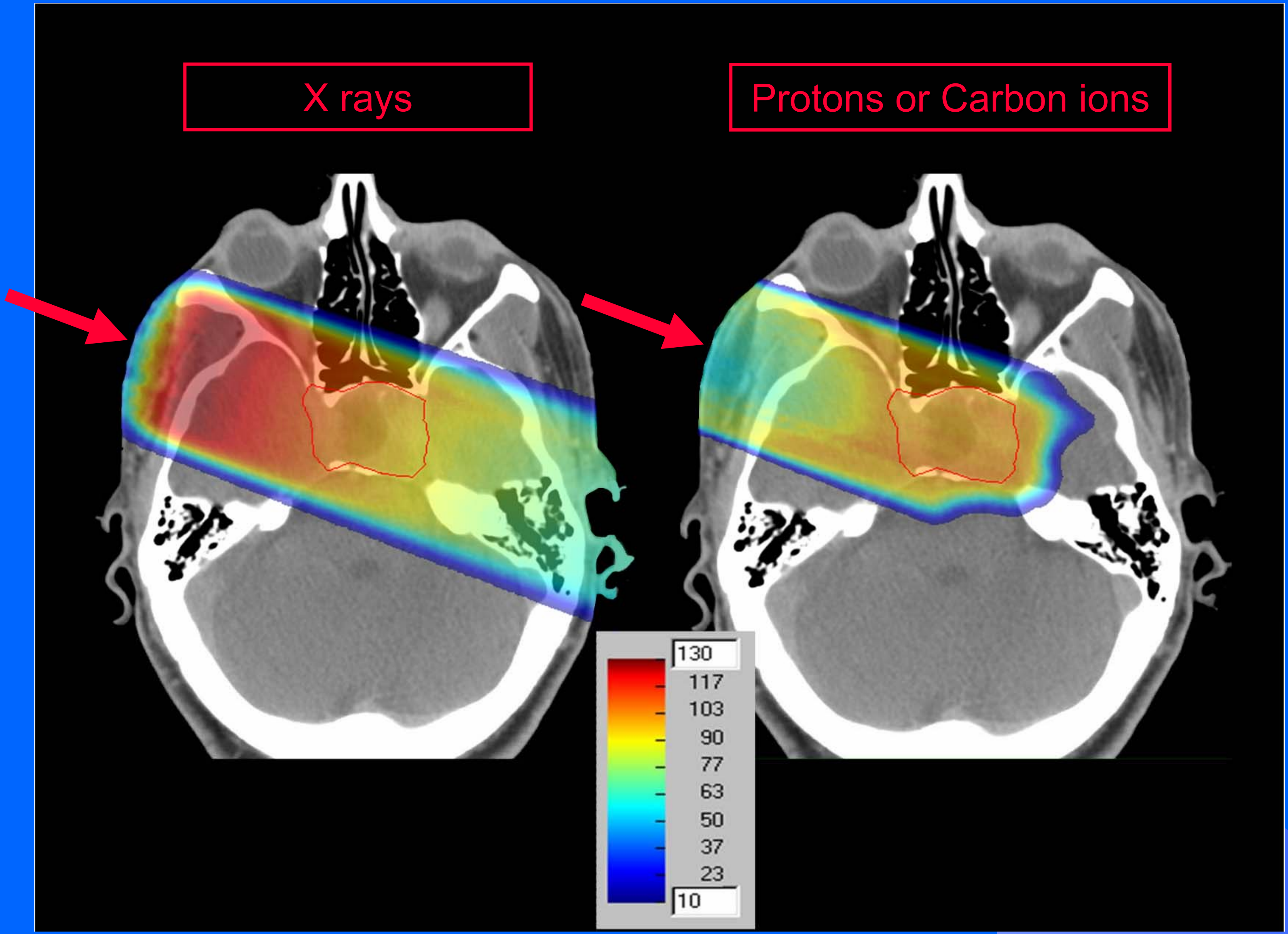




Medical applications

Cancer hadron-therapy

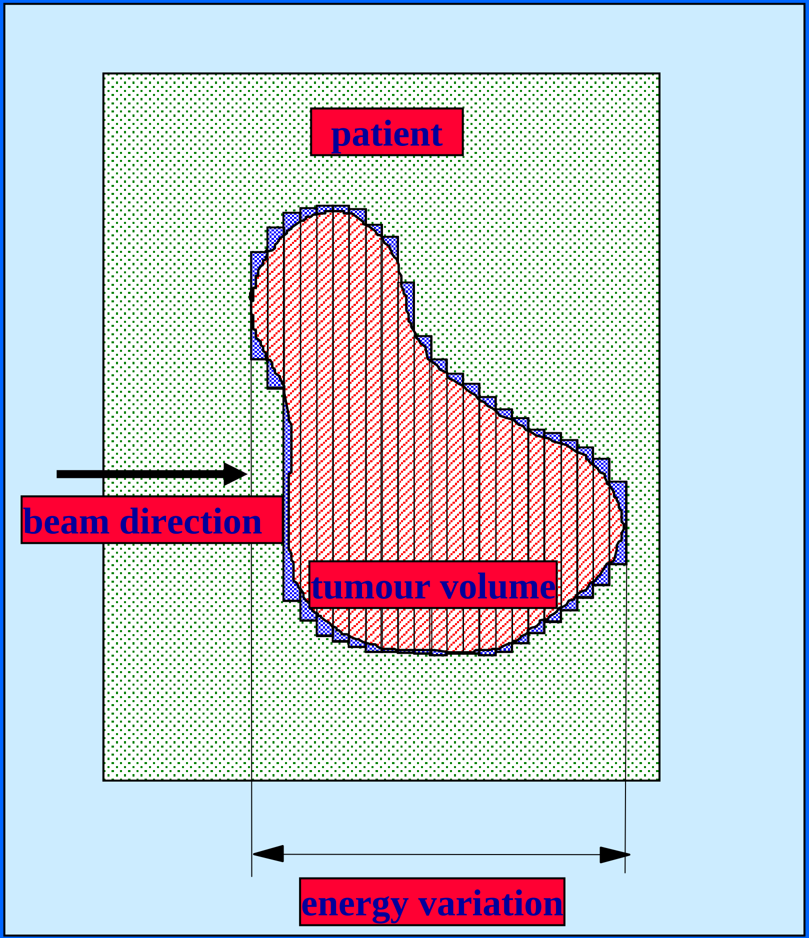
Single beam comparison

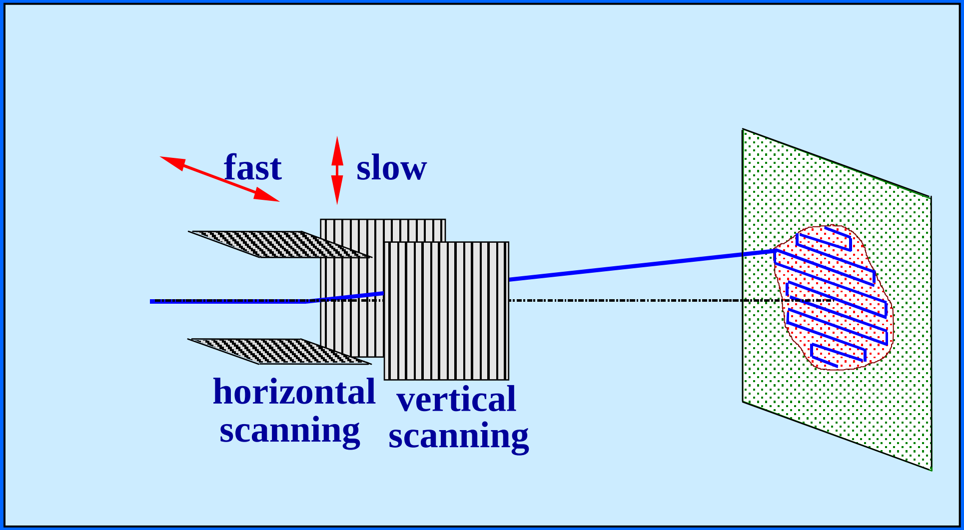


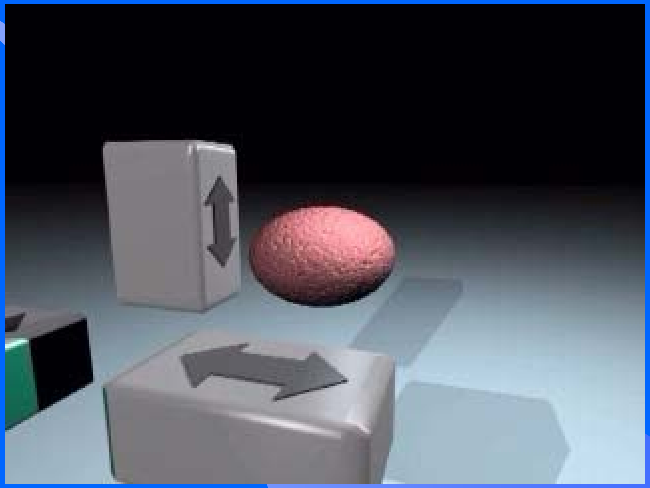
The basic principles of hadron-therapy

- First idea:
  - Bob Wilson, 1946
- Bragg peak
  - Better conformity of the dose to the target → healthy tissue sparing
- Hadrons are charged
  - Beam scanning for dose distribution
- Heavy ions
  - Higher biological effectiveness

Active scanning

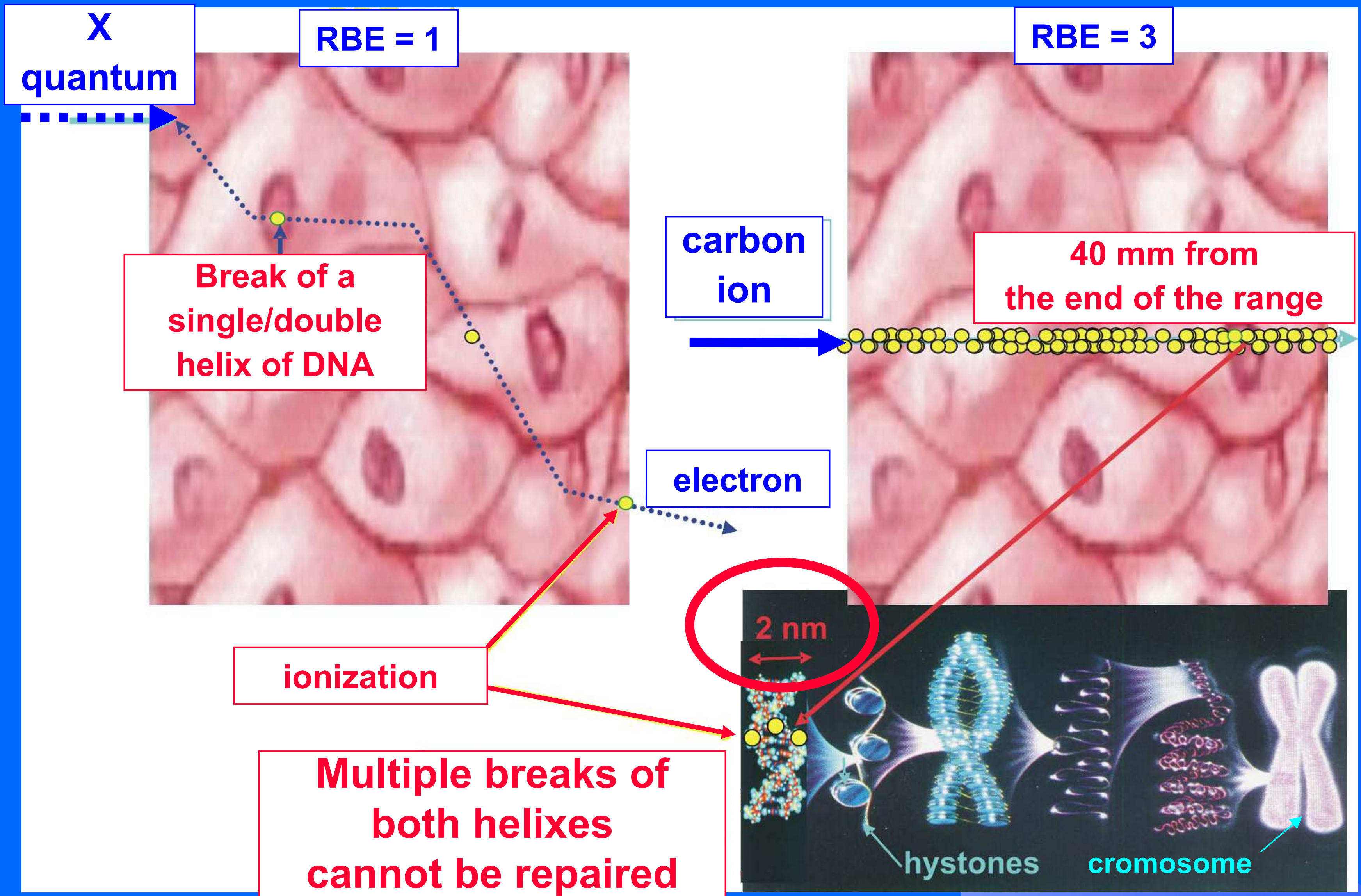






New technique developed mainly at GSI and PSI

Why ions have a large biological effectiveness?

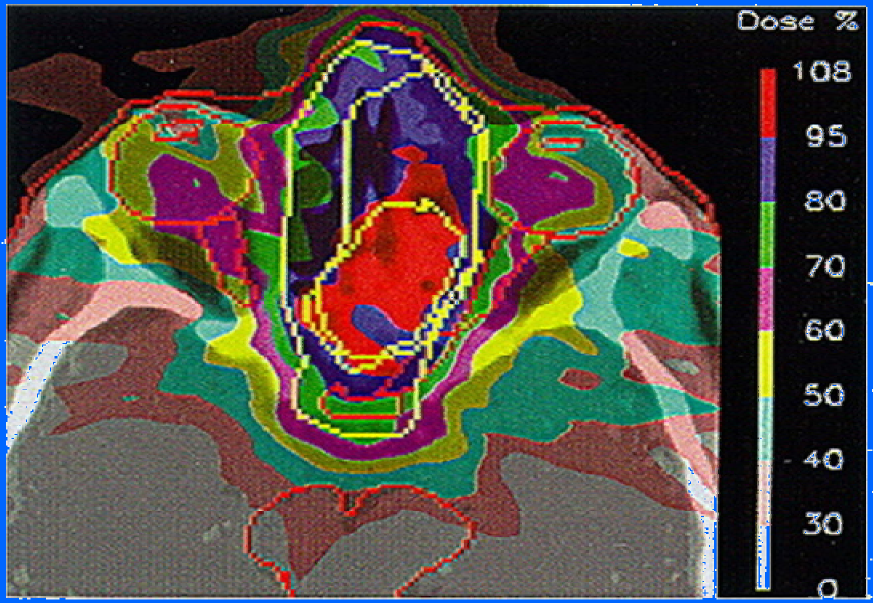


Multiple breaks of both helixes cannot be repaired

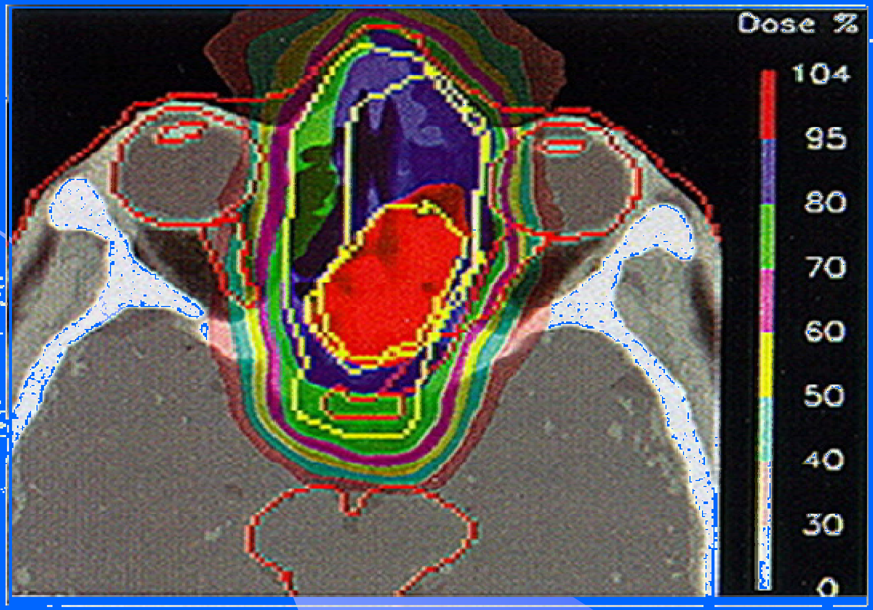
Protons and ions are more precise than X-rays

Tumour between the eyes

9 X –ray beams



1 proton beam



Number of potential patients

X-ray therapy every 10 million inhabitants: 20'000 pts/year

Protontherapy

12% of X-ray patients = 2'400 pts/year

Therapy with Carbon ions for radio-resistant tumour

3% of X-ray patients = 600 pts/year

Every 50 M inhabitants

- Proton-therapy

4-5 centres

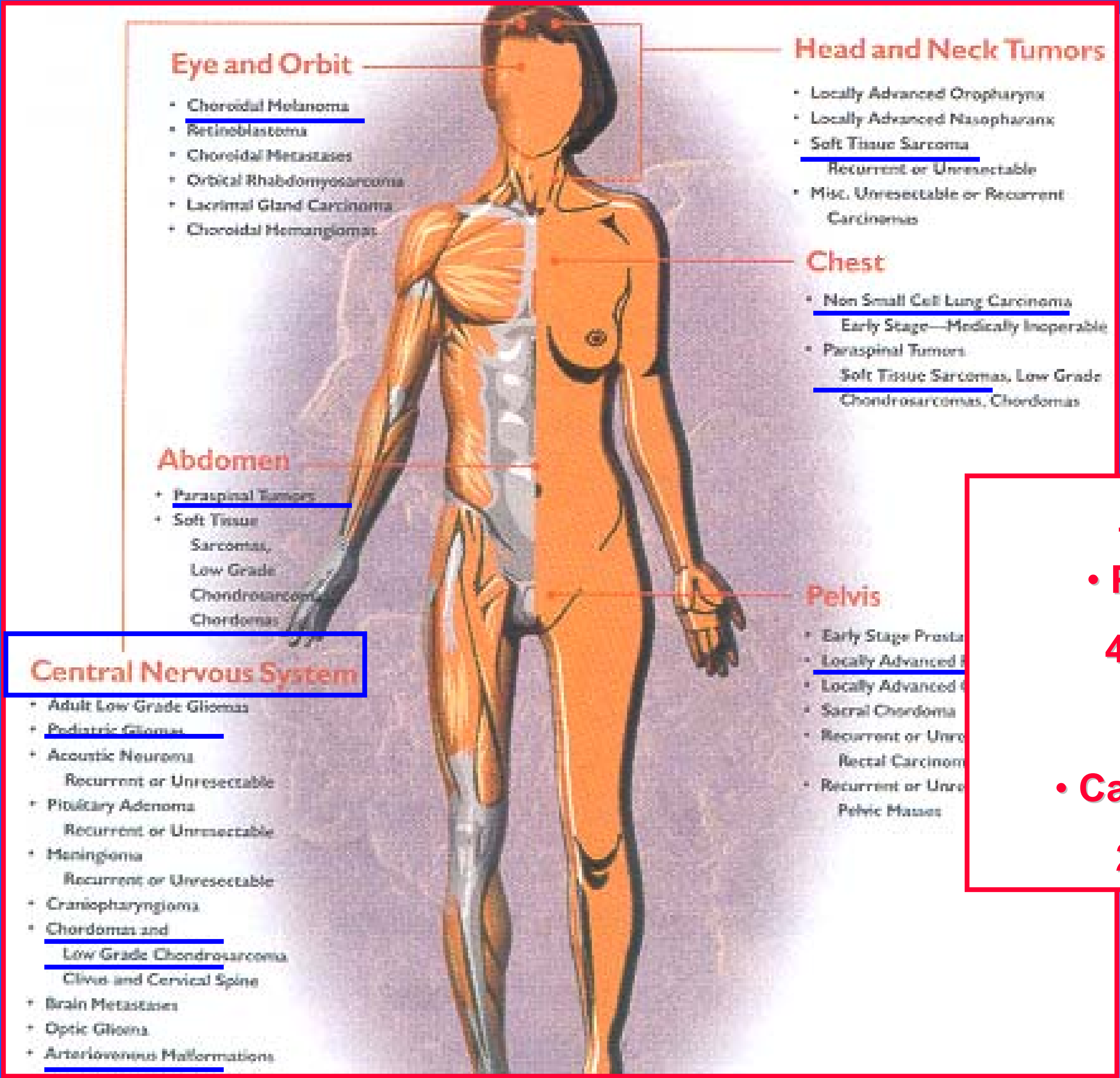
- Carbon ion therapy

1 centre

TOTAL about 3'000 pts/year

every 10 M

The sites



<u>Up to present</u>

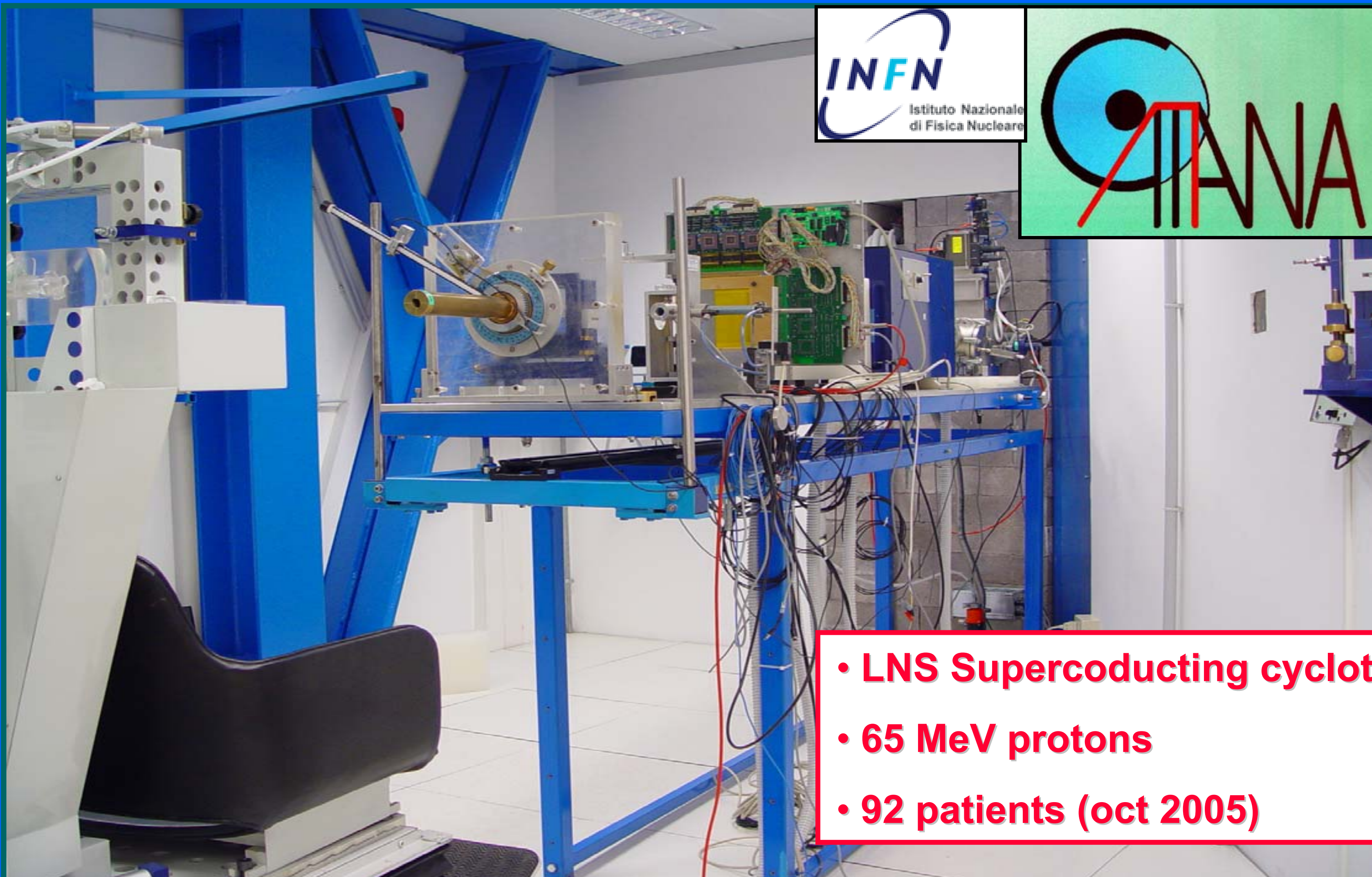
- **Proton-therapy: 40 000 patients**
- **Carbon ion therapy 2 200 patients**

Present and "near" future of hadrontherapy

- **Proton-therapy is "booming"!** *(for information see PTCOG, ptcog.web.psi.ch)*
  - Laboratory based centres: Orsay, PSI, INFN-Catania, …
  - Hospital based centres: 3 in USA, 4 in Japan and many under construction (USA, Japan, Germany, China, Korea, …)
  - Companies offer turn-key centers (cost: 50-60 M Euro)

- **Carbon ion therapy**
  - 2 hospital based centres in Japan
  - Pilot project at GSI
  - 2 hospital based centres under construction in Germany and Italy
  - 2 projects approved (France and Austria)
  - European network ENLIGHT

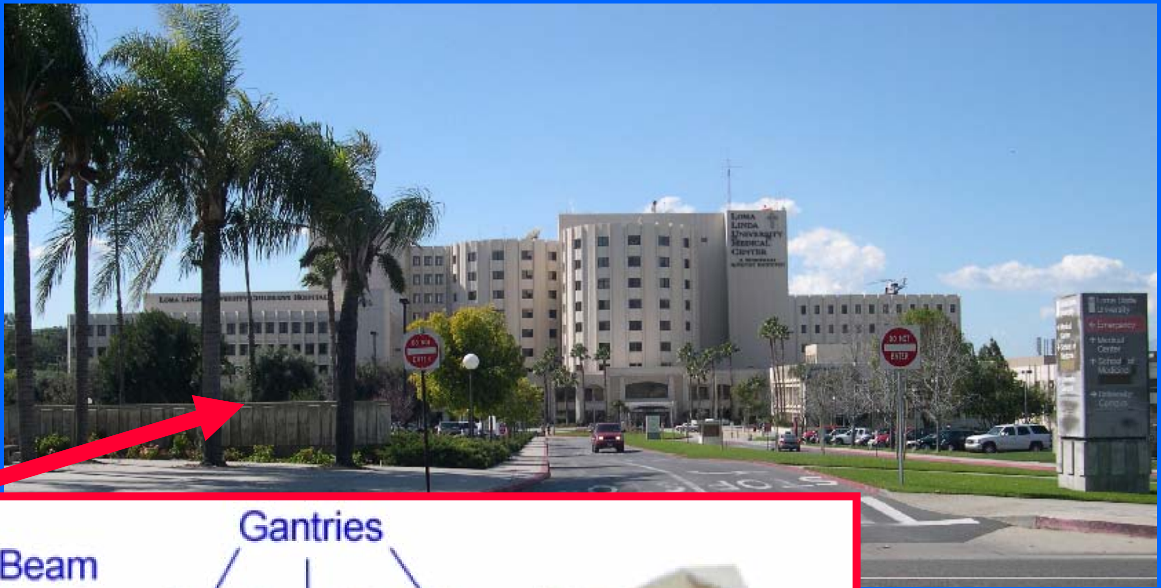
The eye melanoma treatment at INFN-LNS in Catania

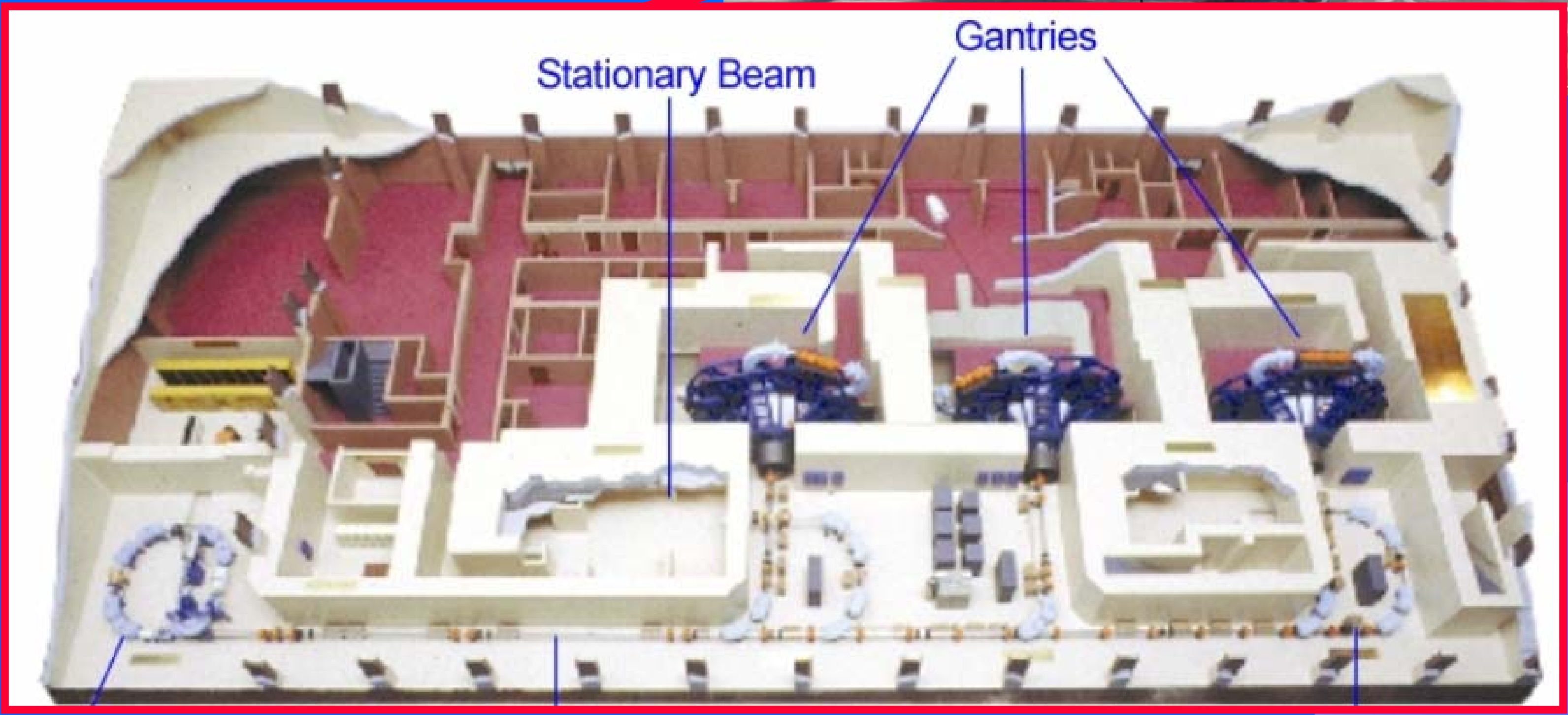


- LNS Supercoducting cyclotron
- 65 MeV protons
- 92 patients (oct 2005)

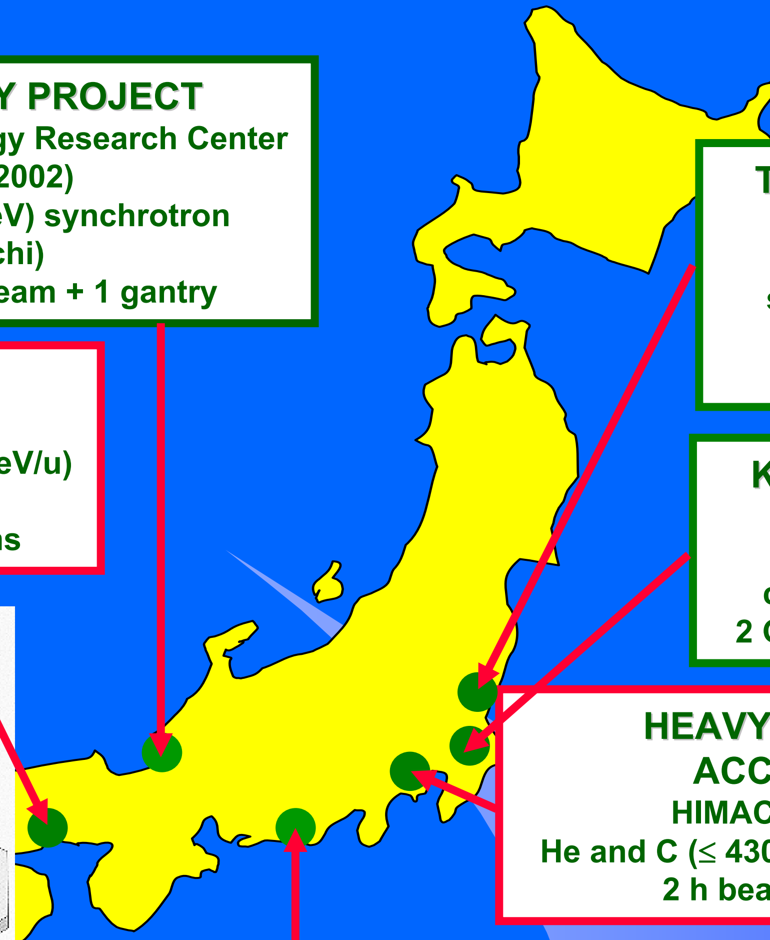
The Loma Linda University Medical Center

- First hospital-based proton-therapy centre, built in 1993
- 160/sessions a day



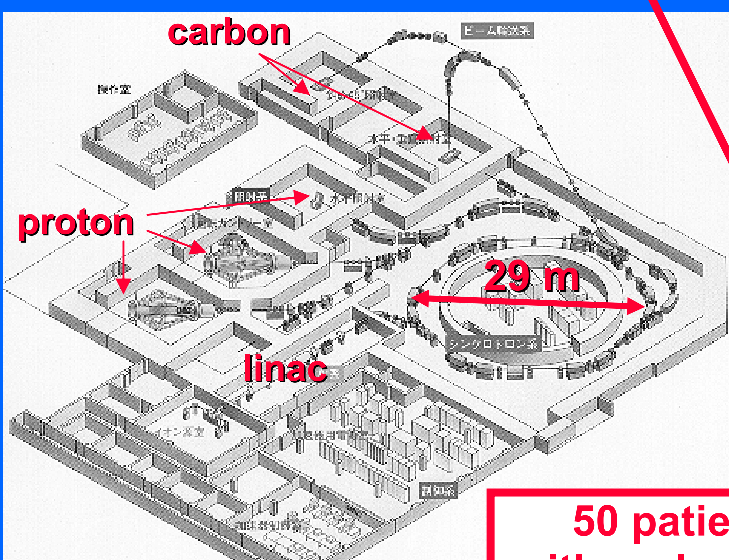


Japan: 4 proton Centres and 2 carbon ion centres



WAKASA BAY PROJECT
by Wakasa-Bay Energy Research Center
Fukui (2002)
protons (≤ 200 MeV) synchrotron
(Hitachi)
1 h beam + 1 v beam + 1 gantry

HYOGO MED CENTRE
Hyogo (2001)
protons (≤ 230 MeV) - He and C ions (≤ 320 MeV/u)
Mitsubishi synchrotron
2 p gantries + 2 fixed p beam + 2 ion rooms



50 patients with carbon ions

TSUKUBA CENTRE
Ibaraki (2001)
protons (≤ 270 MeV)
synchrotron (Hitachi)
2 gantries
2 beam for research

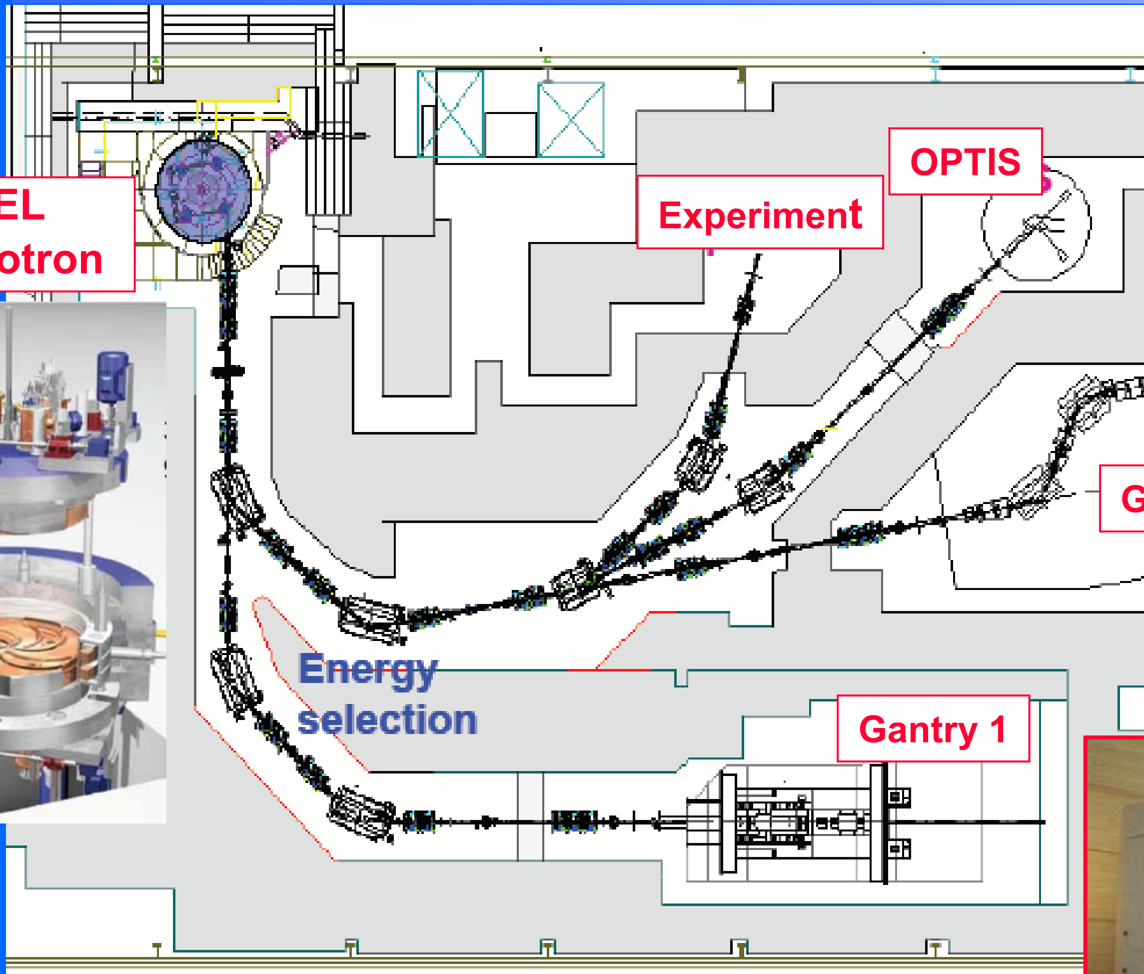
KASHIWA CENTER
Chiba (1998)
protons (≤ 235 MeV)
cyclotron (IBA – SHI)
2 Gantries + 1 hor. beam

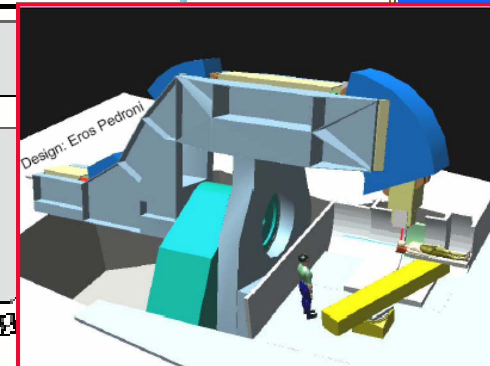
HEAVY ION MEDICAL ACCELERATOR
HIMAC of NIRS (1995)
He and C (≤ 430 MeV/u) 2 synchrotrons
2 h beams + 2 v beams

2000 patients with carbon ions

SHIZUOKA FACILITY
Shizuoka (2002)
Proton synchrotron
2 gantries + 1 h beam

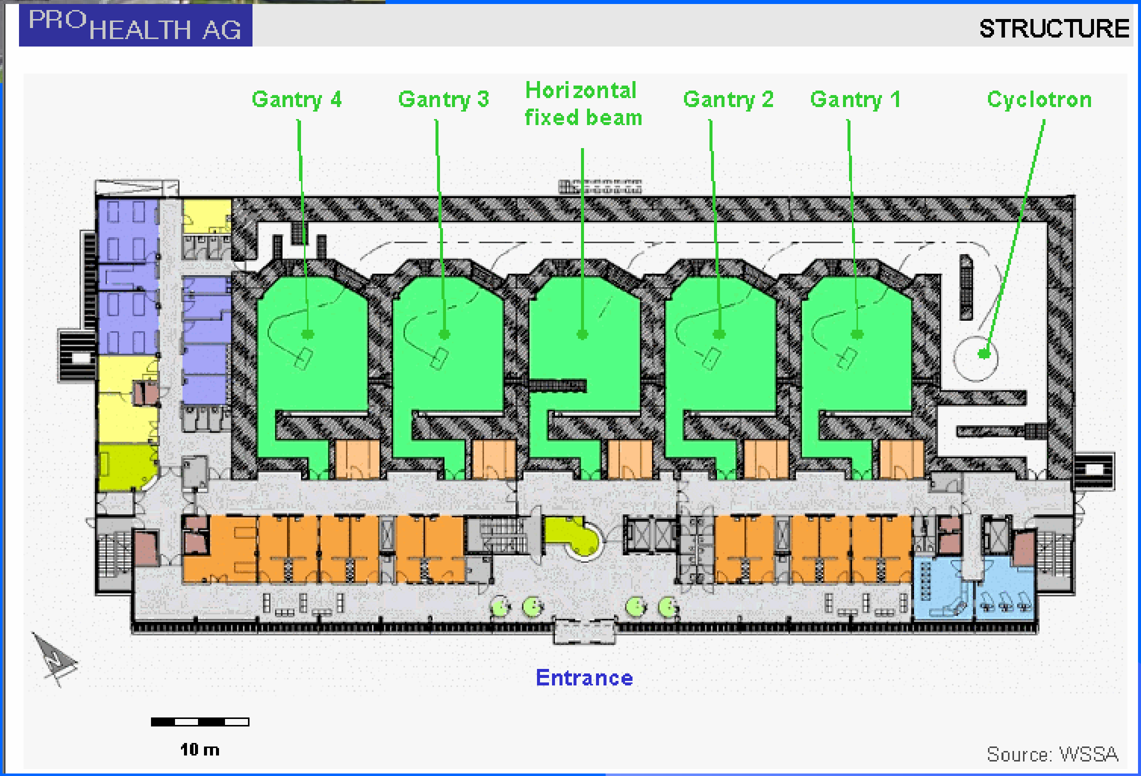
PROSCAN project at PSI





- New SC 250 MeV proton cyclotron – Installed
- New proton gantry

Rinecker - Munich



Almost ready !

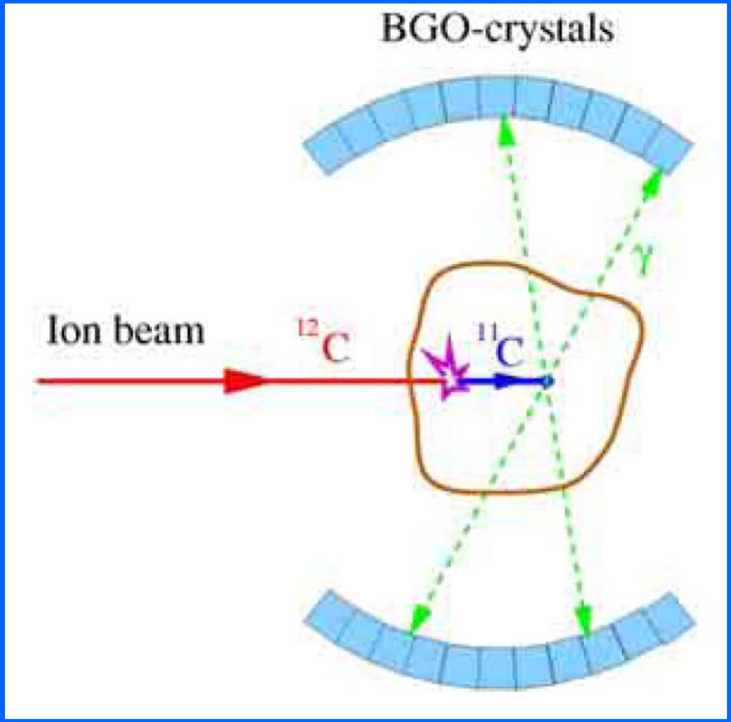
Carbon ion therapy in Europe

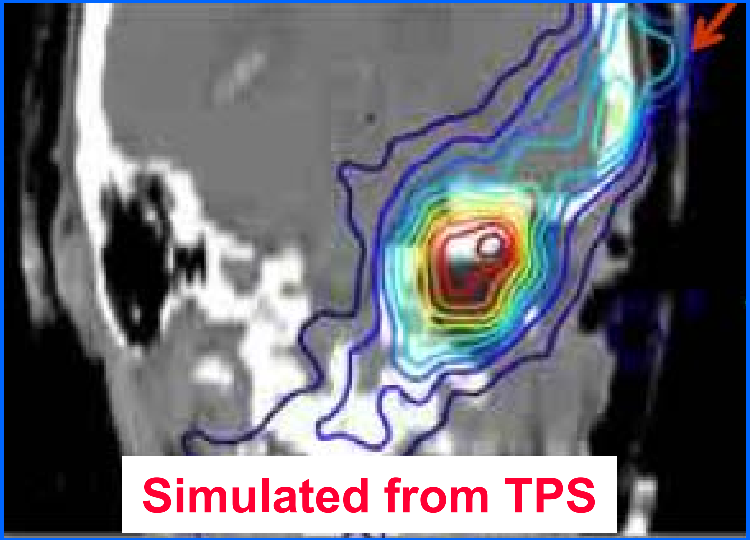
1998 - GSI pilot project (G. Kraft)

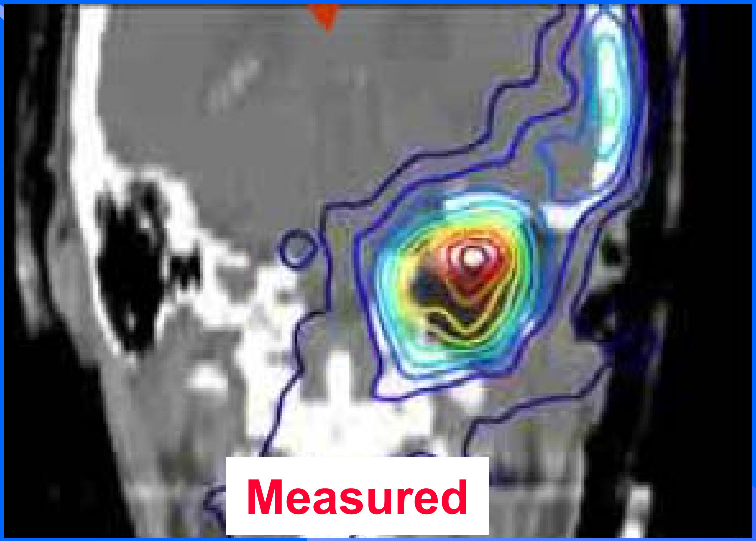
200 patients treated with carbon ions

PET on-line

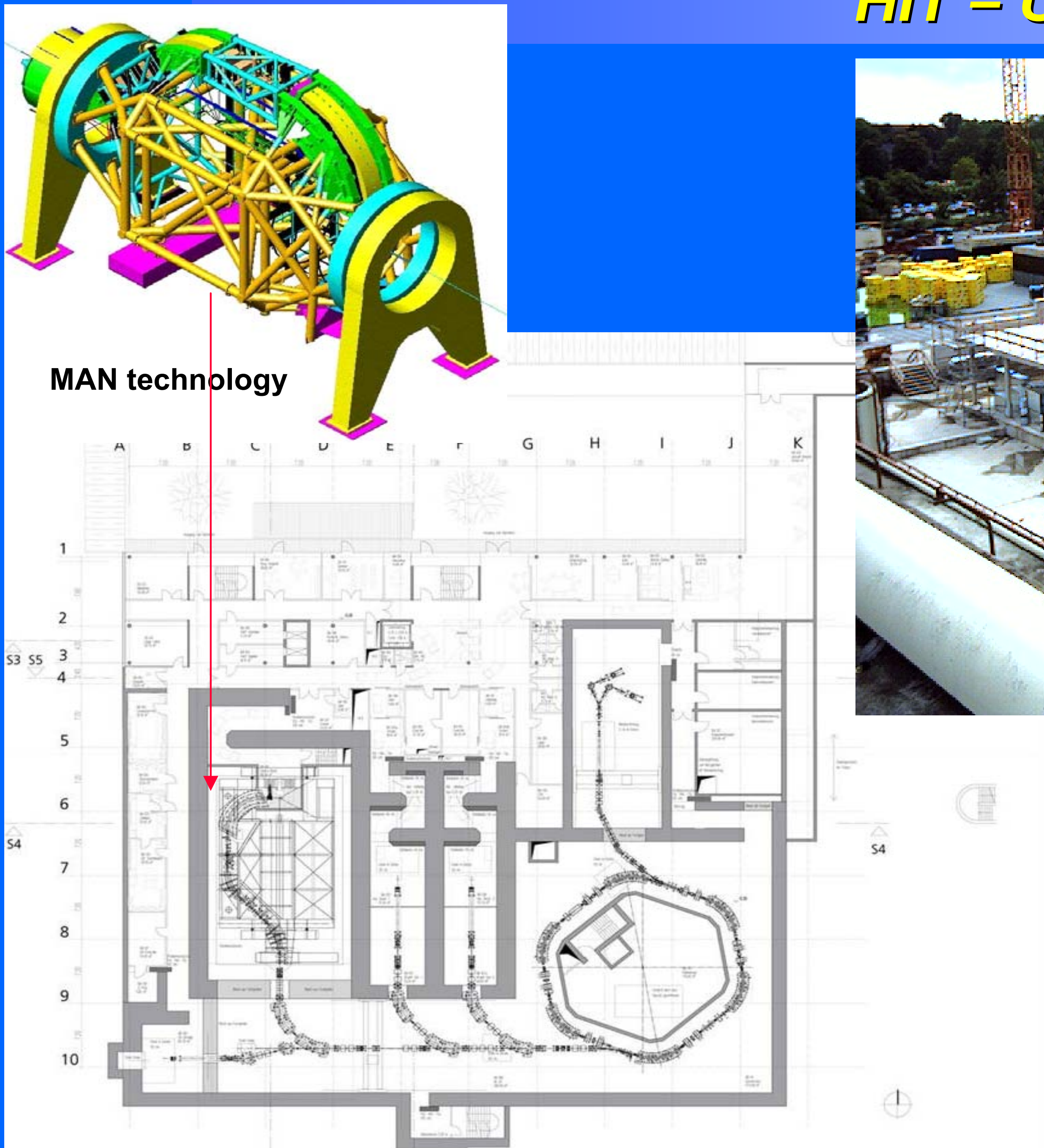
PET on-line







HIT – University of Heidelberg



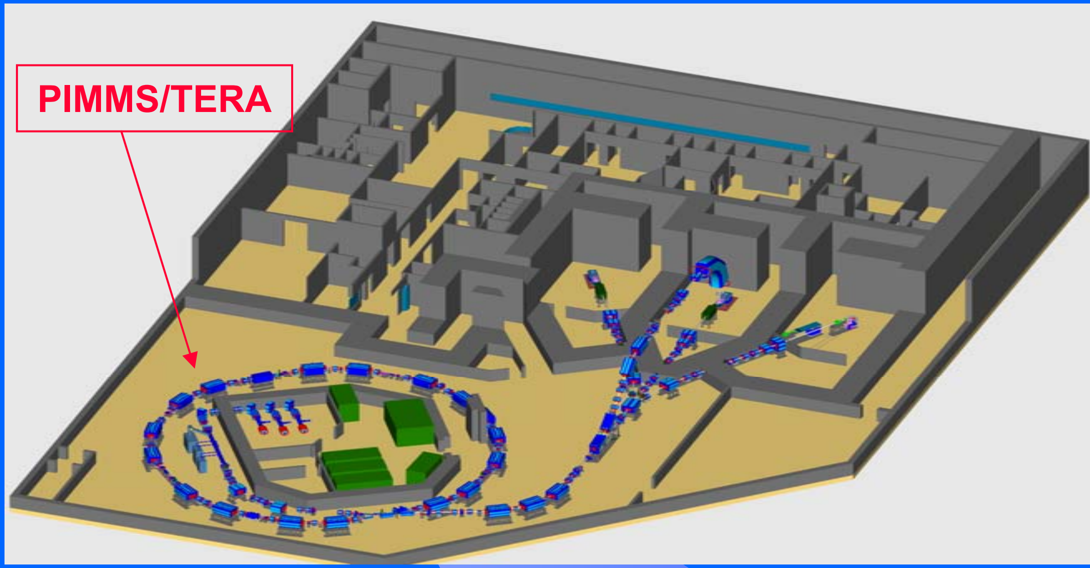
- Project started in 2001
- First patient treatment foreseen in 2007

The TERA Foundation

- Not-for-profit foundation created in 1992 by Ugo Amaldi and recognized by the Italian Ministry of Health in 1994

- Research in the field of particle accelerators and detectors for hadron-therapy

- First goal: the Italian National Centre (CNAO) now under construction in Pavia



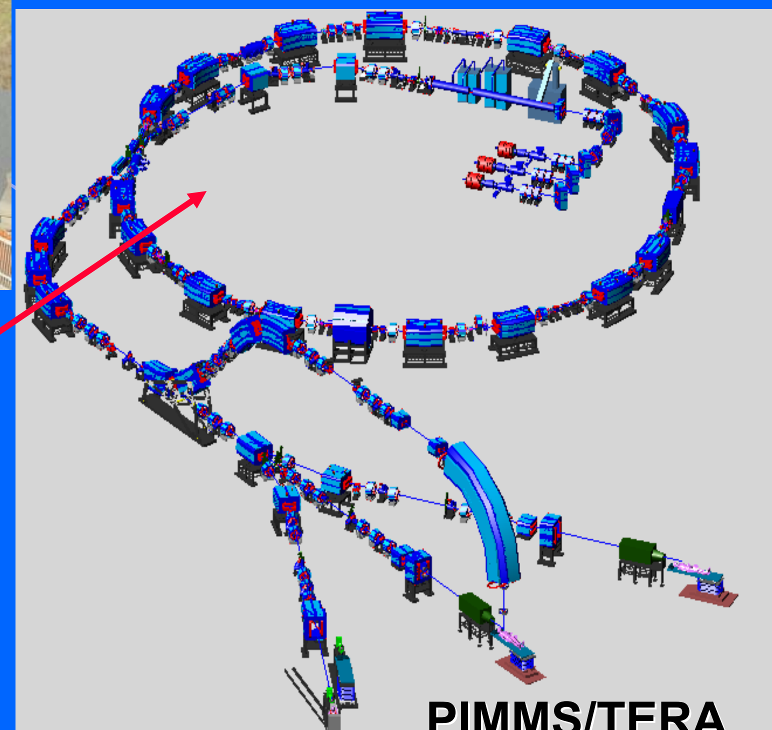
- Collaborations with many research institutes and universities
  - in particular CERN, INFN, PSI, GSI, JRC, Universities of Milan, Turin and Piemonte Orientale

CNAO on the Pavia site

- Investment: 75 M€
- Main source of funds:

Italian Health Ministry

- Ground breaking: March 2005
- Treatment of the first patient foreseen by the end of 2007



CNAO

January 21st, 2006

… end of February, 2006

Courtesy S. Rossi

Medium term

- "Dual" cyclotrons for protons and carbon ions
- CYCLINAC = Cyclotron + LINAC

Long term

- Laser plasma accelerators

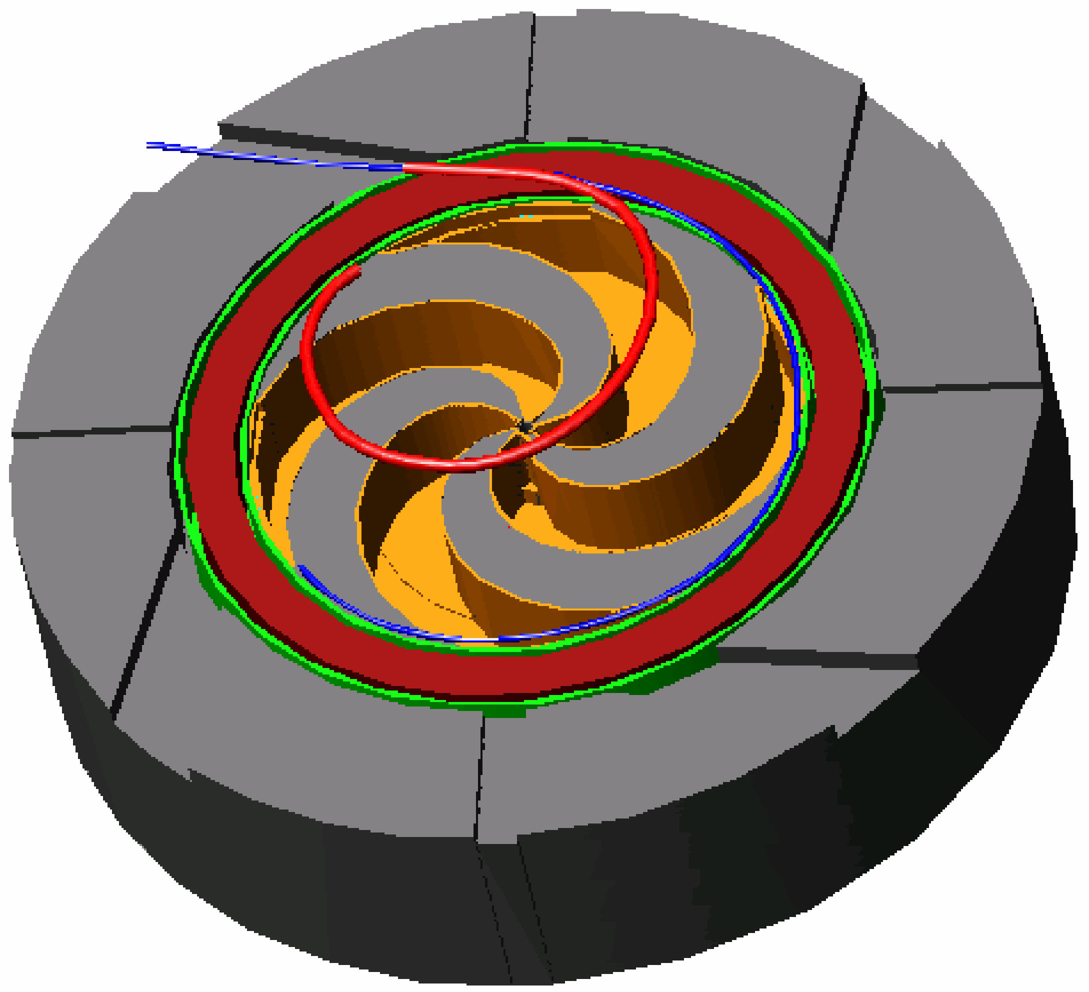
250 MeV/u SC cyclotron

- H_2^+ molecules

  250 MeV proton beam for deep seated cancer treatment

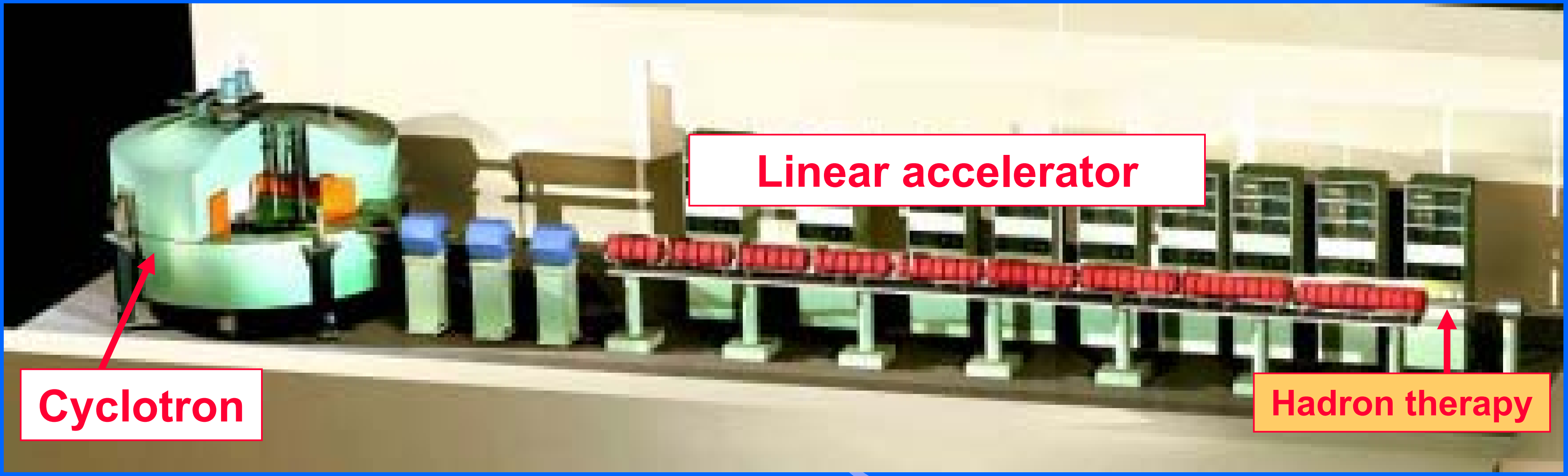
- 250 MeV/u fully stripped C ions

  maximum penetration of 12 cm in water



INFN – ACCEL – AnsaldoSuperconduttori

The CYCLINAC: the new project of TERA

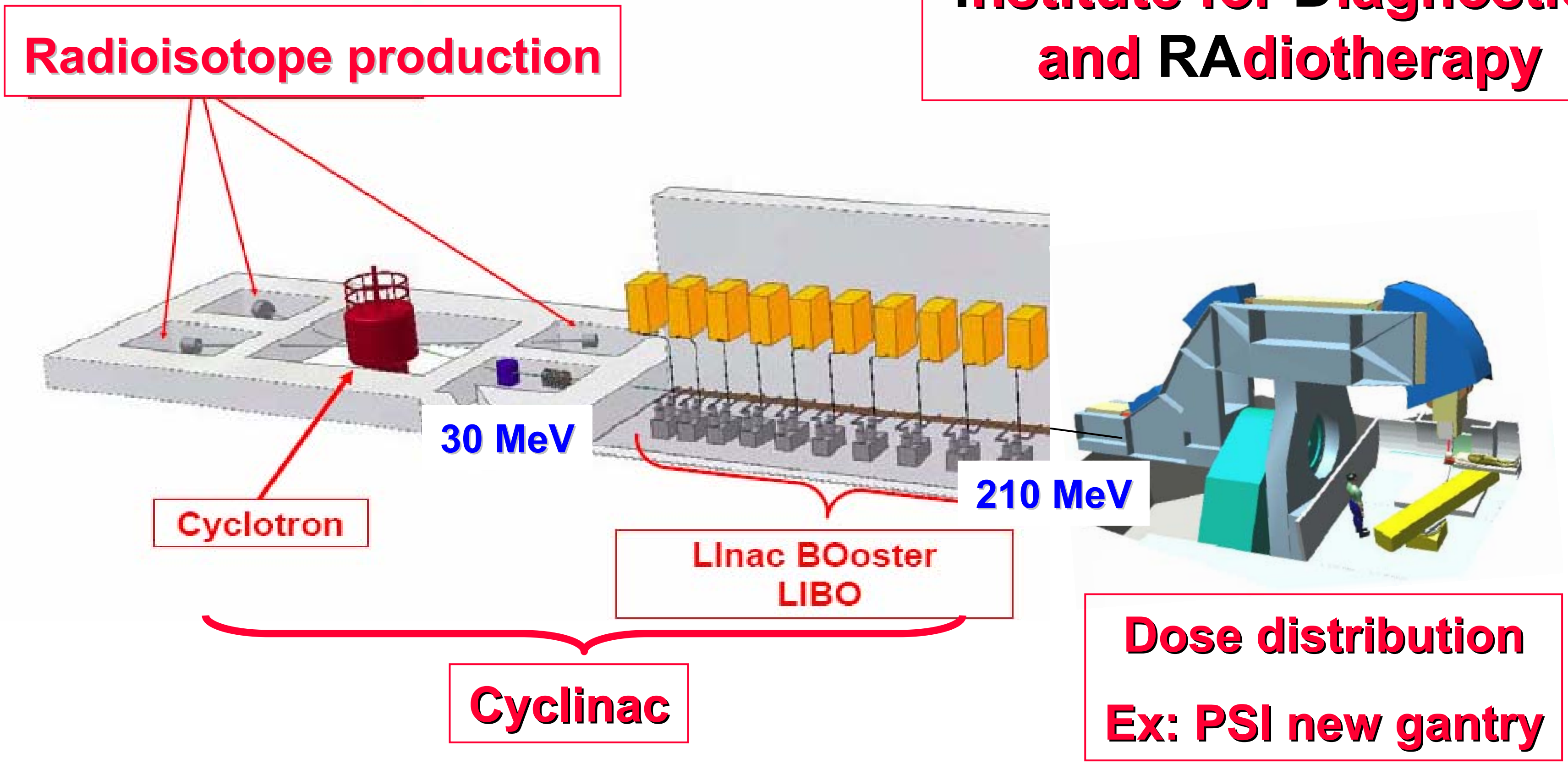


- CYCLINAC = CYClotron + LINAC
- Commercial cyclotron for the production of radioisotopes
- Linac to boost the beam energy for hadron-therapy

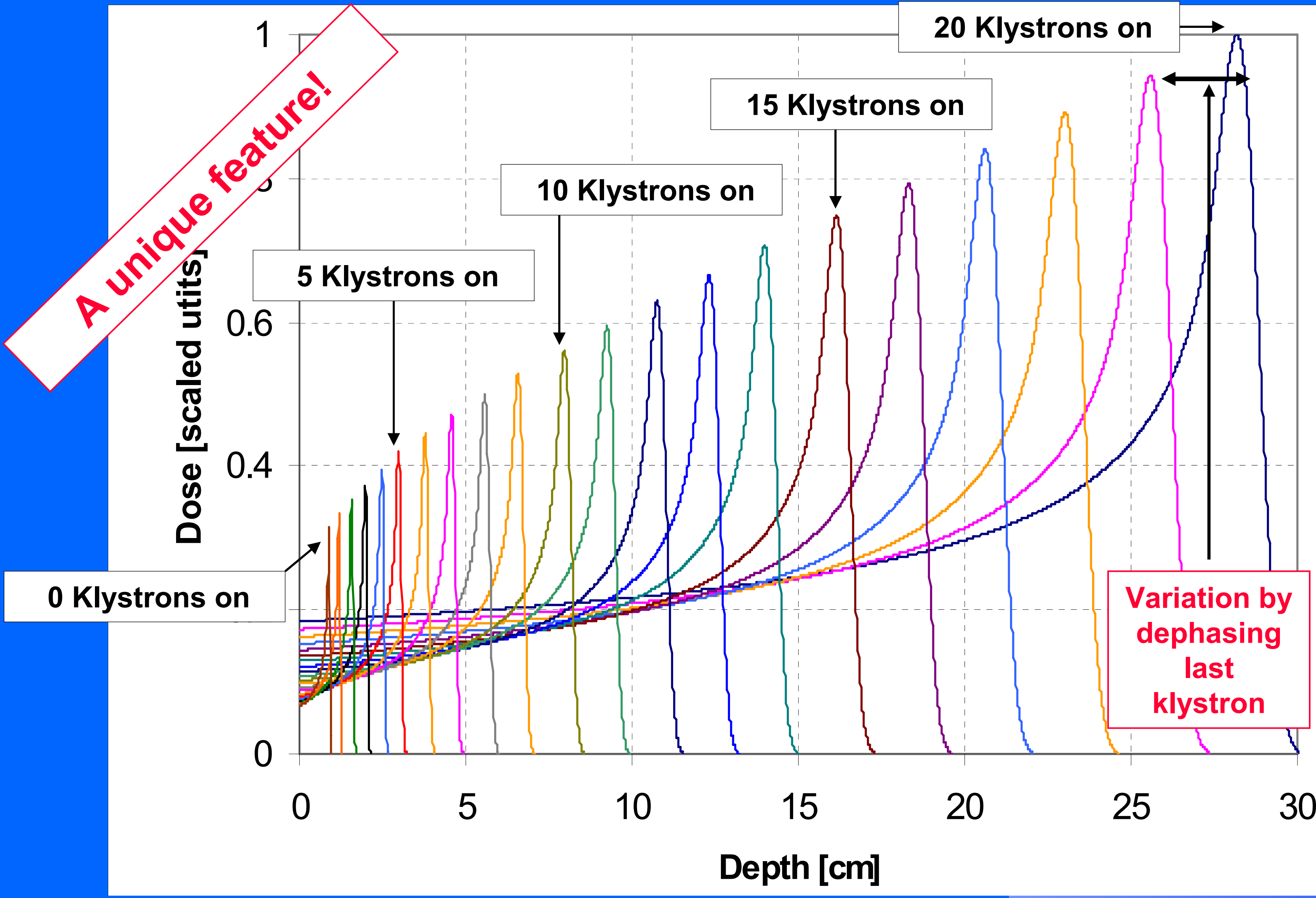
Two main functions

DIAGNOSTICS + THERAPY

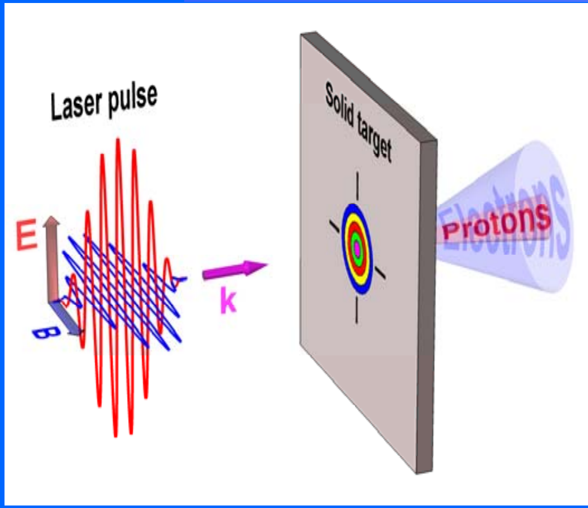
Institute for Diagnostics and RAdiotherapy

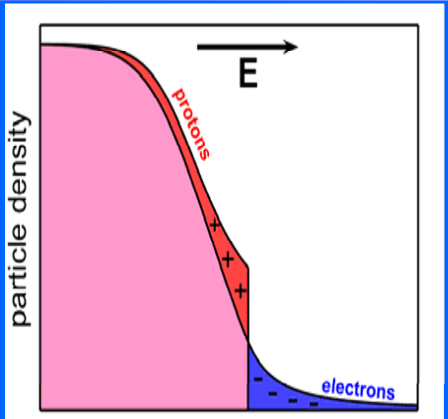


Bragg curves obtained by switching off klystrons



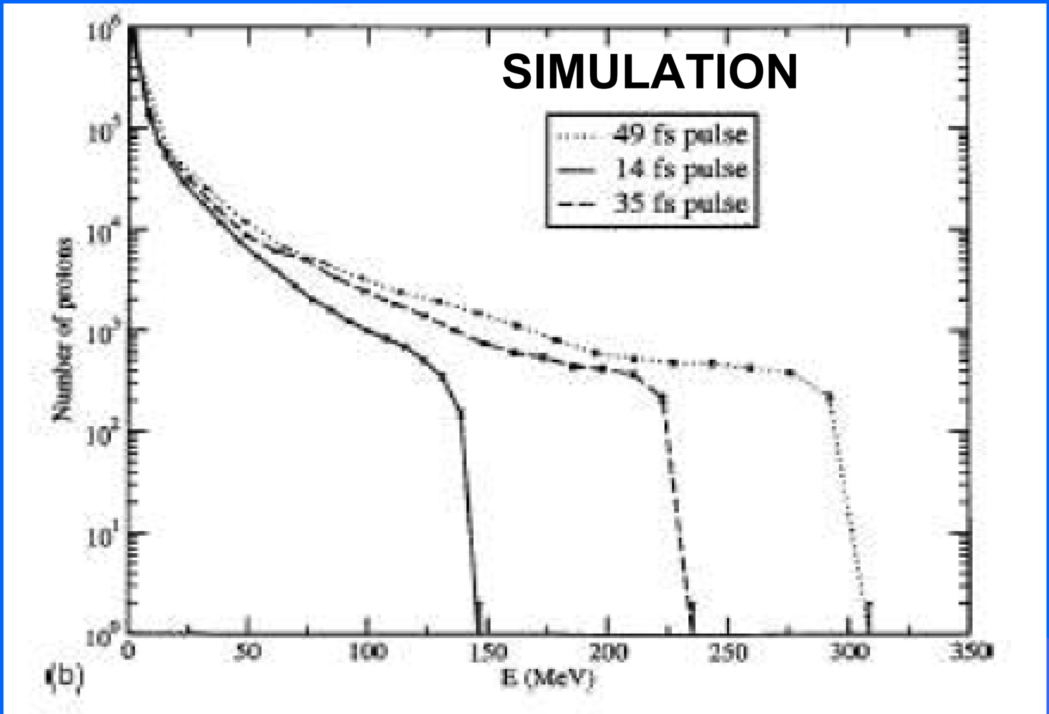
The long term future: laser - plasma “accelerators”?





The mechanism

- ~ 10^{13} protons measured
- Proton energy: 58 MeV (LLNL)



- Laser: 50 fs, 50 J (Petawatt!)
- $I = 10^{21}$ W/cm^2
- >10^{11} protons up to 300 MeV

MANY YEARS OF WORK

Suitable for protontherapy?

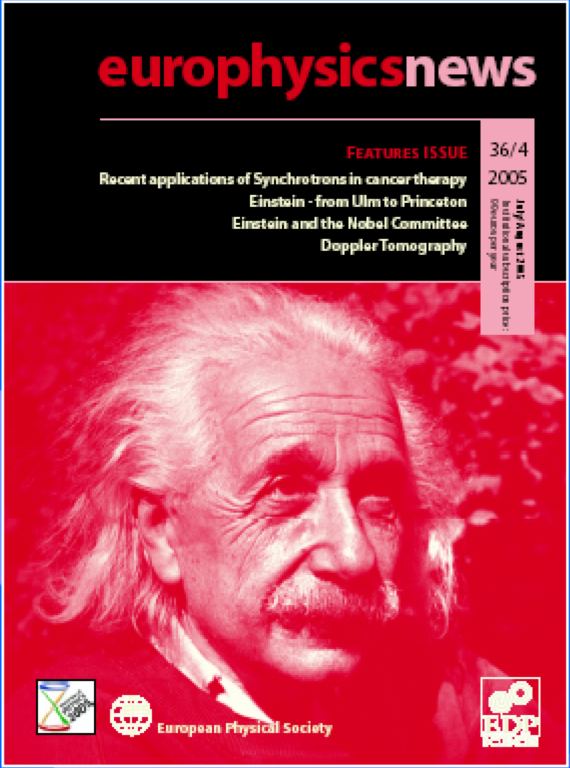
- Is the number of protons reproducible from pulse to pulse?
- Is it possible to control the intensity of the proton beam?
- Moreover the beam is neither monochromatic nor well collimated (with respect to standard accelerators)

New ideas are needed, in particular for an “ad hoc” dose distribution system

Conclusions and Outlook

- **Hadrontherapy is becoming a reality!**
  - **Proton therapy is "booming"**
  - **Many carbon ion facilities are under construction or approved**
  - **Still a lot of R&D is needed in the near future**

- **For more information:**
  - **U. Amaldi and G. Kraft, on Europhysics News**



Work is in progress…

Physics is beautiful…

…and useful !